

Notes to all students taking:

- 1. Foundation of Chemistry II**
- 2. Or Chemistry for petroleum Engineers II**

The following pages illustrate the kind of problems you may be asked. Please read through it as it forms an excellent explanations to the material covered in most topics covered.

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Gases

12.1 UNITS OF PRESSURE AND TEMPERATURE

Warning: In all gas-law equations temperature must be expressed in Kelvin (K).

12.1 Express the following gas pressures in atm:

(a) 300 cmHg (b) 28 lb/in.² (c) 380 torr (d) 0.760 torr (e) 7.60 torr.

■

$$\begin{array}{ll} (a) \quad (300 \text{ cmHg}) \left(\frac{1 \text{ atm}}{76.0 \text{ cmHg}} \right) = 3.95 \text{ atm} & (b) \quad \left(\frac{28 \text{ lb}}{\text{in.}^2} \right) \left(\frac{1 \text{ atm}}{14.7 \text{ lb/in.}^2} \right) = 1.9 \text{ atm} \\ (c) \quad (380 \text{ torr}) \left(\frac{1 \text{ atm}}{760 \text{ torr}} \right) = 0.500 \text{ atm} & (d) \quad (0.760 \text{ torr}) \left(\frac{1 \text{ atm}}{760 \text{ torr}} \right) = 0.00100 \text{ atm} \\ (e) \quad (7.60 \text{ torr}) \left(\frac{1 \text{ atm}}{760 \text{ torr}} \right) = 0.0100 \text{ atm} \end{array}$$

12.2 How high a column of air would be necessary to cause the barometer to read 76 cmHg if the atmosphere were of uniform density 1.2 kg/m³? The

$$\begin{aligned} \text{Pressure of Hg} &= \text{pressure of air} \\ (\text{Height of Hg}) \times (\text{density of Hg}) \times (g) &= (\text{height of air}) \times (\text{density of air}) \times (g) \\ (0.76 \text{ m})(13\,600 \text{ kg/m}^3) &= (h)(1.2 \text{ kg/m}^3) & h = \frac{(0.76 \text{ m})(13\,600 \text{ kg/m}^3)}{1.2 \text{ kg/m}^3} = 8.6 \text{ km} \end{aligned}$$

density of mercury is $13.6 \times 10^3 \text{ kg/m}^3$.

■

12.3 Calculate the difference in pressure between the top and bottom of a vessel 76.00 cm deep when filled at 25°C is 13.53 g/cm^3 ; of water, 0.997 g/cm^3 .

- (a) Pressure = height $\times$ density $\times g = (0.7600 \text{ m})(997 \text{ kg/m}^3)(9.81 \text{ m/s}^2) = 7.43 \times 10^3 \text{ Pa} = 7.43 \text{ kPa}$
- (b) Pressure = $(0.7600 \text{ m})(13\,530 \text{ kg/m}^3)(9.81 \text{ m/s}^2) = 100.9 \times 10^3 \text{ Pa} = 100.9 \text{ kPa}$

(b) Pressure = $(0.7600 \text{ m})(13\,530 \text{ kg/m}^3)(9.81 \text{ m/s}^2) = 100.9 \times 10^3 \text{ Pa} = 100.9 \text{ kPa}$

12.4 The Rankine scale is an absolute temperature scale which has degrees the same size as on the Fahrenheit scale. What is the freezing point of water in $^{\circ}\text{R}$?

- The size of a Kelvin is 180/100 times as great as the size of each $^{\circ}\text{R}$, since there is a 180° difference between the freezing point and normal boiling point of water on the Rankine scale, and 100K difference.

12.5 Calculate the mass of mercury in a uniform column 760 mm high and 1.00 cm^2 in cross-sectional area. Calculate the mass of mercury in a column of equal height but with 2.00 cm^2 cross-sectional area. Compare the pressures at the bases of the two columns. (The density of mercury is 13.6 g/cm^3 .)

$$760 \text{ mm} = 76.0 \text{ cm}$$

$$V = \text{area} \times \text{height} = (1.00 \text{ cm}^2)(76.0 \text{ cm}) = 76.0 \text{ cm}^3 \quad (76.0 \text{ cm}^3) \left(\frac{13.6 \text{ g}}{\text{cm}^3} \right) = 1030 \text{ g} = 1.03 \text{ kg}$$

In a 2.00 cm^2 column, there would be twice the volume, hence twice the mass of mercury. That mass would rest on twice the area and so exert the same pressure. The pressure does not depend on the cross section of the tube, but only on the vertical height of the mercury.

12.6 Express the standard atmosphere in (a) bars (b) pounds force per square inch.

$$1 \text{ atm} = 101325 \text{ Pa} = 101325 \text{ N/m}^2$$

$$1 \text{ bar} = 10^5 \text{ Pa}$$

$$1$$

lbf

$$1 \text{ atm} = (101325 \text{ Pa}) \left(\frac{1 \text{ bar}}{10^5 \text{ Pa}} \right) = 1.01325 \text{ bar}$$

$$1 \text{ atm} = \left(\frac{101325 \text{ N}}{\text{m}^2} \right) \left(\frac{1 \text{ lbf}}{4.448 \text{ N}} \right) \left(\frac{1 \text{ m}}{100 \text{ cm}} \right)^2 \left(\frac{2.54 \text{ cm}}{1 \text{ in.}} \right)^2 = \frac{14.70 \text{ lbf}}{\text{in.}^2}$$

$$4.448 \text{ N}$$

▪

12.7 The vapor pressure of water at 25°C is 23.8 torr. Express this in (a) atm

(b) kPa. (a) $(23.8 \text{ torr}) \left(\frac{1 \text{ atm}}{760 \text{ torr}} \right) = 0.0313 \text{ atm}$ (b) $(0.0313 \text{ atm}) \left(\frac{101.325 \text{ kPa}}{\text{atm}} \right) = 3.17 \text{ kPa}$

▪ 1

12.8 Camphor has been found to undergo a crystalline modification at a

$$3.09 \times 10^9 \text{ N/m}^2 = (3.09 \times 10^9 \text{ Pa}) \left(\frac{1 \text{ atm}}{101325 \text{ Pa}} \right) = 3.05 \times 10^4 \text{ atm}$$

temperature of 148°C and a pressure of $3.09 \times 10^9 \text{ N/m}^2$. What is the transition pressure in atm?

▪

12.9 An abrasive, borazon, is made by heating ordinary boron nitride to 3000°F at one million lb/in^2 . Express the experimental conditions in $^\circ\text{C}$ and atm.

▪ $\left(\frac{1.00 \times 10^6 \text{ lbf}}{\text{in.}^2} \right) \left(\frac{1 \text{ atm}}{14.7 \text{ lbf/in.}^2} \right) = 6.80 \times 10^4 \text{ atm}$ $^\circ\text{C} = \left(\frac{5}{9} \right) (^\circ\text{F} - 32^\circ) = \left(\frac{5}{9} \right) (3000^\circ - 32^\circ) = 1650^\circ\text{C}$

12.10 In a satellite flyby of Mercury in 1974, the planet's atmospheric

$$(2 \times 10^{-9} \text{ mbar}) \left(\frac{10^{-3} \text{ bar}}{\text{mbar}} \right) \left(\frac{10^5 \text{ Pa}}{\text{bar}} \right) \left(\frac{1 \text{ atm}}{101\,325 \text{ Pa}} \right) = 2 \times 10^{-12} \text{ atm}$$

pressure was observed to be 2×10^{-9} mbar. What fraction is this of the earth's atmospheric pressure?

▪

12.11 (a) Show how the value of R in $\text{L} \cdot \text{atm}/\text{K} \cdot \text{mol}$ can be derived from the value in SI units. (b) Express R in calories.

$$\begin{aligned} (a) \quad R &= 8.314 \text{ J/K} \cdot \text{mol} = (8.314 \text{ N} \cdot \text{m}/\text{K} \cdot \text{mol}) \left(\frac{1 \text{ atm}}{1.013 \times 10^5 \text{ N/m}^2} \right) \left(\frac{10^3 \text{ dm}^3}{1 \text{ m}^3} \right) \left(\frac{1 \text{ L}}{\text{dm}^3} \right) \\ &= 0.0821 \text{ L} \cdot \text{atm}/\text{K} \cdot \text{mol} \end{aligned}$$

$$(b) \quad R = (8.314 \text{ J/K} \cdot \text{mol}) \left(\frac{1 \text{ cal}}{4.184 \text{ J}} \right) = 1.987 \text{ cal/K} \cdot \text{mol}$$

12.2 BOULE'S LAW, CHARLES' LAW, COMBINED GAS LAW

12.12 A 10.0cm column of air trapped by a column of Hg 8.00 cm long in a capillary tube of uniform bore when the tube is held horizontally in a room at 0.9400 atm pressure (fig. 12.11). What will be the length of the air column when the tube is held (a) vertically with the open end (b) vertically with the open end down (c) at a 45° angle from vertical with the open end up?

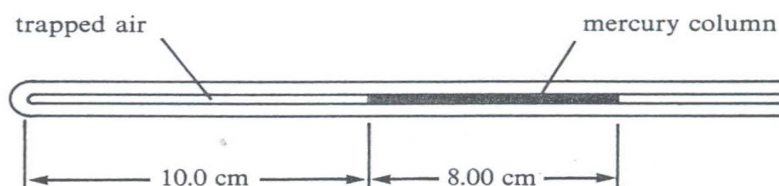


Fig. 12.1

- A convenient pressure unit here is the mmHg = torr. Thus, the given barometric pressure is

$$(0.9400 \text{ atm}) \left(\frac{760.0 \text{ torr}}{1 \text{ atm}} \right) = 714.4 \text{ torr}$$

The volume of trapped air is equal to its length l times the (constant) cross-sectional area A . At constant temperature $P_1 V_1 = P_2 V_2 = P_1 l_1 A = P_2 l_2 A$ $P_1 l_1 = P_2 l_2$ for a given mass of gas,

- (a) The weight of mercury represents an increase in the pressure on the gas of
 $8.00 \text{ cmHg} = 80.0 \text{ mmHg} = 80.0 \text{ torr}.$

$$P_2 = (714.4 \text{ torr}) + (80.0 \text{ torr}) = 794.4 \text{ torr}$$

$$l_2 = \frac{P_1 l_1}{P_2} = \frac{(714.4 \text{ torr})(10.0 \text{ cm})}{794.4 \text{ torr}} = 8.99 \text{ cm}$$

- (b) The weight of the mercury decreases the pressure by 80.0 torr.

$$P_2 = 634.4 \text{ torr} \quad l_2 = \frac{(714.4 \text{ torr})(10.0 \text{ cm})}{634.4 \text{ torr}} = 11.3 \text{ cm}$$

- (c) The weight of the mercury is borne partially by the gas and partially by the glass. The vertical height of the mercury is a measure of the additional pressure on the gas. A 45° right triangle

$$(714.4 \text{ torr}) + (56.6 \text{ torr}) = 771.0 \text{ torr} \quad l_2 = \frac{(714.4 \text{ torr})(10.0 \text{ cm})}{771.0 \text{ torr}} = 9.27 \text{ cm}$$

has sided in the ration 1:1: . Thus the vertical height = (80.0mm)/

$$\sqrt{2} = 56.6 \text{ mm. The pressure is}$$

12.13 A 1.00 L sample of gas at 760 torr is compressed to 0.800 L at constant temperature. Calculate the final pressure of the gas.

$$PV = k = (760 \text{ torr})(1.00 \text{ L}) = 760 \text{ torr} \cdot \text{L}$$

But after compression, $PV = k$, $P(0.800 \text{ L}) = 760 \text{ torr} \cdot \text{L}$ thus $P = 950 \text{ torr}$

12.14 Calculate the volume which 4.00 L of gas at 0°C will occupy at 100°C and the same pressure.

$$V_1 = k'T_1 \quad 4.00 \text{ L} = k'(0^\circ + 273^\circ) = k'(273 \text{ K}) \quad k' = 0.01465 \text{ L/K}$$

New conditions: $V_2 = k'T_2 \quad V_2 = (0.01465 \text{ L/K})[(100 + 273) \text{ K}] = 5.46 \text{ L}$

Note that temperature must be expressed in Kelvin's. This calculation may be done by combining the separate steps, as follows:

$$\frac{V_1}{T_1} = k' = \frac{V_2}{T_2} \quad V_2 = \frac{V_1 T_2}{T_1} = \frac{(4.00 \text{ L})(373 \text{ K})}{273 \text{ K}} = 5.46 \text{ L}$$

12.15 A sample of gas occupies 2.00 L at 760 torr. Calculate the volume it will occupy at 1.25 atm and the same temperature.

	1	2	
P	1.00 atm 760 torr	1.25 atm	$P_1 V_1 = P_2 V_2 \quad V_2 = \frac{P_1 V_1}{P_2} = \frac{(1.00 \text{ atm})(2.00 \text{ L})}{1.25 \text{ atm}} = 1.60 \text{ L}$
V	2.00 L	V_2	

12.16 Calculate the temperature at which a 2.00 L sample of gas at 27°C would occupy 3.00 L if its pressure were changed from 1.00 atm to 800 torr.

	1	2	
P	1.00 atm	(800/760) atm	$\frac{P_1 V_1}{T_1} = \frac{P_2 V_2}{T_2} \quad \frac{T_1}{P_1 V_1} = \frac{T_2}{P_2 V_2}$
V	2.00 L	3.00 L	$T_2 = \frac{T_1 P_2 V_2}{P_1 V_1} = \frac{(300 \text{ K})[(800/760) \text{ atm}](3.00 \text{ L})}{(1.00 \text{ atm})(2.00 \text{ L})} = 474 \text{ K}$
T	300 K	T_2	

12.17 A 4.00 L sample of gas at 30°C and 1.00 atm is changed to 0°C and 800 torr. What is its new volume?

	1	2	
P	1.00 atm	(800/760) atm	$V_2 = \frac{P_1 V_1 T_2}{P_2 T_1} = \frac{(1.00 \text{ atm})(4.00 \text{ L})(273 \text{ K})}{[(800/760) \text{ atm}](303 \text{ K})}$
V	4.00 L	V_2	$= 3.42 \text{ L}$
T	303 K	273 K	

12.18 A sample of gas at 1.20 atm and 27°C is heated at constant pressure to 57°C.

Its

	1	2
P	1.20 atm	1.20 atm
V	V_1	4.75 L
T	300 K	330 K

From Charles' law:

$$V_1 = \frac{V_2 T_1}{T_2} = \frac{(4.75 \text{ L})(300 \text{ K})}{330 \text{ K}} = 4.32 \text{ L}$$

final

volume is 4.75 L. What was its original volume?

▪

12.19 At what temperature does a sample of gas occupy 4.00 L at 1.11 atm, if it initially occupied 2.22 L at 1.00 atm and 60°C?

	1	2	
P	1.00 atm	1.11 atm	$\frac{P_1 V_1}{T_1} = \frac{P_2 V_2}{T_2}$
V	2.22 L	4.00 L	$\frac{T_1}{P_1 V_1} = \frac{T_2}{P_2 V_2}$
T	333 K	T_2	$T_2 = \frac{T_1 P_2 V_2}{P_1 V_1} = \frac{(333 \text{ K})(1.11 \text{ atm})(4.00 \text{ L})}{(1.00 \text{ atm})(2.22 \text{ L})} = 666 \text{ K}$

▪

12.20 A sample of gas at 0°C and 1.00 atm pressure occupies 2.50 L. What change in temperature is necessary to adjust the pressure of that gas to 1.50 atm after it has been transferred to a 2.00 L container?

▪
$$\frac{P_1 V_1}{T_1} = \frac{P_2 V_2}{T_2} \quad T_2 = \frac{P_2 V_2 T_1}{P_1 V_1} = \frac{(1.50 \text{ atm})(2.00 \text{ L})(0^\circ + 273^\circ)}{(1.00 \text{ atm})(2.50 \text{ L})} = 328 \text{ K}$$

Hence, an increase in temperature of 55 K, from 273 K to 328K, is required.

12.21 Consider several samples of gas undergoing change as described in the table below. Determine the missing value for each sample.

	initial conditions			final conditions		
	pressure	volume	temperature	pressure	volume	temperature
(a)	760 torr	1.00 L	25 °C	760 torr	_____	200 °C
(b)	1.00 atm	500 mL	127 °C	_____	200 mL	127 °C
(c)	1.23 atm	700 mL	250 K	650 torr	_____	200 °C
(d)	600 lb/in. ²	3.25 L	300 K	_____	1.75 L	100 °C
(e)	_____	1.00 L	300 K	700 torr	3000 mL	400 K
(f)	800 torr	7.50 L	300 K	_____	2.25 L	350 K

- (a) P is constant. Hence, $V_2 = V_1 T_2 / T_1 = (1.00 \text{ L})(473 \text{ K}) / (298 \text{ K}) = 1.59 \text{ L}$
- (b) T is constant. Hence, $P_2 = P_1 V_1 / V_2 = (1.00 \text{ atm})(500 \text{ mL}) / (200 \text{ mL}) = 2.50 \text{ atm}$
- (c) $V_2 = \frac{P_1 V_1 T_2}{T_1 P_2} = \frac{(1.23 \text{ atm})(700 \text{ mL})(473 \text{ K})}{(250 \text{ K})(\frac{650}{760} \text{ atm})} = 1900 \text{ mL} = 1.90 \text{ L}$
- (d) $P_2 = \frac{P_1 V_1 T_2}{T_1 V_2} = \frac{(600 \text{ lb/in.}^2)(3.25 \text{ L})(373 \text{ K})}{(300 \text{ K})(1.75 \text{ L})} = 1390 \text{ lb/in.}^2$
- (e) $P_1 = \frac{P_2 V_2 T_1}{T_2 V_1} = \frac{(700 \text{ torr})(3.00 \text{ L})(300 \text{ K})}{(400 \text{ K})(1.00 \text{ L})} = 1580 \text{ torr}$
- (f) $P_2 = \frac{P_1 V_1 T_2}{T_1 V_2} = \frac{(800 \text{ torr})(7.50 \text{ L})(350 \text{ K})}{(300 \text{ K})(2.25 \text{ L})} = 3110 \text{ torr}$

12.22 A mass of oxygen occupies 7.00 L under a pressure of 740 torr. Determine the volume of the same mass of gas at standard pressure, the temperature remaining constant.

- Standard pressure is 760 torr. Boyle's law gives

$$P_1 V_1 = P_2 V_2 \quad \text{or} \quad V_2 = \frac{P_1}{P_2} V_1 = \left(\frac{740 \text{ torr}}{760 \text{ torr}} \right) (7.00 \text{ L}) = 6.82 \text{ L}$$

12.23 An ideal gas initially at 710 torr and 30.0 °C occupies 2600 mL.

Calculate the final temperature if the conditions are changed to a pressure of 1.20 atm and a volume of 3.20 L.

- Both values of P as well as those for V must be expressed in the same units for use in the combined gas law.

$$T_2 = \frac{P_2 V_2 T_1}{P_1 V_1} = \frac{(1.20 \text{ atm})(760 \text{ torr/atm})(3.20 \text{ L})(303 \text{ K})}{(710 \text{ torr})(2.60 \text{ L})} = 479 \text{ K} = 206 \text{ °C}$$

12.24 A mass of neon occupies 400 mL at 100°C. Find its volume at 0°C, the pressure remaining constant.

- Charles' law gives

$$\frac{V_1}{T_1} = \frac{V_2}{T_2} \quad \text{or} \quad V_2 = \frac{T_2}{T_1} V_1 = \frac{(0 + 273) \text{ K}}{(100 + 273) \text{ K}} (400 \text{ mL}) = 293 \text{ mL}$$

12.25 A steel tank contains carbon dioxide at 27°C and is at a pressure of 11.0 atm. Determine the internal gas pressure when the tank and its contents are heated to 100°C.

- Gay-Lissac's law gives

$$\frac{P_1}{T_1} = \frac{P_2}{T_2} \quad \text{or} \quad P_2 = \frac{T_2}{T_1} P_1 = \left(\frac{(100 + 273) \text{ K}}{(27 + 273) \text{ K}} \right) (11.0 \text{ atm}) = 13.7 \text{ atm}$$

12.26 When 2.00 L of gas at 760 torr and 27°C is expanded to 3.00 L at 77°C

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$$P_2 = \frac{P_1 V_1 T_2}{T_1 V_2} = \frac{(760 \text{ torr})(2.00 \text{ L})(350 \text{ K})}{(3.00 \text{ L})(300 \text{ K})} = 591 \text{ torr}$$

what will the final pressure be?

▪

12.27 Given 20.0 L of ammonia at 15°C and 760 torr. Determine its volume at 50°C and 800 torr.

- The combined gas law gives (15°C = 288 K, 50°C = 323 K):

$$\frac{P_1 V_1}{T_1} = \frac{P_2 V_2}{T_2} \quad \text{or} \quad V_2 = V_1 \left(\frac{T_2}{T_1} \right) \left(\frac{P_1}{P_2} \right) = (20.0 \text{ L}) \left(\frac{323 \text{ K}}{288 \text{ K}} \right) \left(\frac{760 \text{ torr}}{800 \text{ torr}} \right) = 21.3 \text{ L}$$

12.28 The volume of a quantity of sulfur dioxide at 18°C and 1500 torr is 4.3 ft³. Calculate its volume at STP.

- STP means 0°C and 760 torr. Converting to absolute temperatures and

$$V_2 = V_1 \left(\frac{T_2}{T_1} \right) \left(\frac{P_1}{P_2} \right) = (4.3 \text{ ft}^3) \left(\frac{273 \text{ K}}{291 \text{ K}} \right) \left(\frac{1500 \text{ torr}}{760 \text{ torr}} \right) = 8.0 \text{ ft}^3 \quad \begin{array}{l} \text{applying} \\ \text{the} \end{array}$$

combined gas law,

12.29 To how many atm pressure must 2.00 L of gas measured at 1.00 atm and -20°C be subjected to be compressed to 0.500 L when the temperature is 40°C ?

- The combined gas law gives

$$\frac{P_1 V_1}{T_1} = \frac{P_2 V_2}{T_2} \quad \text{or} \quad P_2 = P_1 \left(\frac{V_1}{V_2} \right) \left(\frac{T_2}{T_1} \right) = (1.00 \text{ atm}) \left(\frac{2.00 \text{ L}}{0.500 \text{ L}} \right) \left(\frac{313 \text{ K}}{253 \text{ K}} \right) = 4.95 \text{ atm}$$

12.30 A mass of oxygen occupies 40 ft^3 at 758 torr. Compute its volume at 700 torr, temperature remaining constant.

- $P_1 V_1 = P_2 V_2 \quad V_2 = \frac{V_1 P_1}{P_2} = (40.0 \text{ ft}^3) \left(\frac{758 \text{ torr}}{700 \text{ torr}} \right) = 43.3 \text{ ft}^3$

12.31 Ten liters of hydrogen under 7.0 atm pressure is contained in a cylinder which has a movable piston. The piston is moved in until the same mass of gas occupies 4.0 L at the same temperature. Find the pressure in the cylinder.

- $P_1 V_1 = P_2 V_2 \quad P_2 = \frac{P_1 V_1}{V_2} = \frac{(7.0 \text{ atm})(10 \text{ L})}{4.0 \text{ L}} = 18 \text{ atm}$

12.32 A given mass of chlorine occupies 25.0 L at 20°C . Determine its

, $\frac{V_1}{T_1} = \frac{V_2}{T_2} \quad V_2 = \frac{V_1 T_2}{T_1} = \frac{(25.0 \text{ L})(45^{\circ} + 273^{\circ})}{20^{\circ} + 273^{\circ}} = 27.1 \text{ L}$ volume at 45°C
pressure

remaining constant.

▪

12.33 A quantity of hydrogen is confined in a chamber of constant volume. When the chamber is immersed in a bath of melting ice, the pressure of the gas is 1000

$$\frac{P_1}{T_1} = \frac{P_2}{T_2}$$

torr. (a) What is the Celsius temperature when the pressure manometer indicates an absolute pressure of 400 torr? (b) What pressure will be indicated when the chamber is brought to 100 °C? (Gay-Lussac's law, or derive from the combined gas law with $V_1 = V_2$.)

Note: Melting ice implies 0 °C.

$$(a) \quad T_2 = \frac{T_1 P_2}{P_1} = \frac{(0^\circ + 273^\circ)(400 \text{ torr})}{1000 \text{ torr}} = 109 \text{ K} = -164^\circ \text{C}$$

$$(b) \quad P_2 = \frac{P_1 T_2}{T_1} = \frac{(1000 \text{ torr})(100^\circ + 273^\circ)}{0^\circ + 273^\circ} = 1.37 \times 10^3 \text{ torr}$$

12.34 Given 1000 ft³ of helium at 15 C and 763 torr, calculate the volume at -6 C and 620 torr.

$$\frac{P_1 V_1}{T_1} = \frac{P_2 V_2}{T_2} \quad V_2 = \frac{P_1 V_1 T_2}{T_1 P_2} = \frac{(763 \text{ torr})(1000 \text{ ft}^3)(267 \text{ K})}{(288 \text{ K})(620 \text{ torr})} = 1140 \text{ ft}^3$$

12.35 A mass of gas at 80 C and 785 torr occupies 350 mL. What volume will the gas occupy at STP?

$$\frac{P_1 V_1}{T_1} = \frac{P_2 V_2}{T_2} \quad V_2 = \frac{P_1 V_1 T_2}{T_1 P_2} = \frac{(785 \text{ torr})(350 \text{ mL})(273 \text{ K})}{(353 \text{ K})(760 \text{ torr})} = 280 \text{ mL}$$

12.36 If a mass of gas occupies 3.00 L at STP, what volume will it occupy at 300 C and 25 atm?

$$\frac{P_1 V_1}{T_1} = \frac{P_2 V_2}{T_2} \quad V_2 = \frac{P_1 V_1 T_2}{T_1 P_2} = \frac{(3.00 \text{ atm})(1.00 \text{ L})(573 \text{ K})}{(273 \text{ K})(25 \text{ atm})} = 0.25 \text{ L}$$

12.37 If a gas occupies 15.7 ft³ at 60C and 14.7 lbf/in², what volume would it occupy at 100 C and 35 lbf/in²?

$$60^\circ \text{F} = \frac{5}{9}(60^\circ - 32^\circ) = 15.6^\circ \text{C} = 289 \text{ K} \quad 100^\circ \text{F} = \frac{5}{9}(100^\circ - 32^\circ) = 37.8^\circ \text{C} = 311 \text{ K}$$

$$\frac{P_1 V_1}{T_1} = \frac{P_2 V_2}{T_2} \quad V_2 = \frac{P_1 V_1 T_2}{T_1 P_2} = \frac{(14.7 \text{ lbf/in}^2)(15.7 \text{ ft}^3)(311 \text{ K})}{(289 \text{ K})(35 \text{ lbf/in}^2)} = 7.1 \text{ ft}^3$$

12.38 A mass of gas occupies 0.825 L at -30°C and 556 Pa. What is the

$$\frac{P_1 V_1}{T_1} = \frac{P_2 V_2}{T_2} \quad P_2 = \frac{P_1 V_1 T_2}{T_1 V_2} = \frac{(556 \text{ Pa})(0.825 \text{ L})(293 \text{ K})}{(243 \text{ K})(2.00 \text{ L})} = 277 \text{ Pa}$$

pressure if the volume becomes 2.00 L and the temperature 20°C ?

▪

12.39 Calculate the final Celsius temperature required to change 10.0 L of helium at 100 K and 0.150 atm to 30.0 L at 0.200 atm.

$$\frac{P_1 V_1}{T_1} = \frac{P_2 V_2}{T_2} \quad P_2 = \frac{P_1 V_1 T_2}{T_1 V_2} = \frac{(556 \text{ Pa})(0.825 \text{ L})(293 \text{ K})}{(243 \text{ K})(2.00 \text{ L})} = 277 \text{ Pa}$$

12.40 One mole of a gas occupies 22.4 L at STP (a) What pressure would be required to compress 1.00 mol of oxygen into a 5.00 L container held at 100°C ? (b) What maximum Celsius temperature would be permitted if this

$$\frac{P_1 V_1}{T_1} = \frac{P_2 V_2}{T_2} \quad \begin{array}{l} \text{amount of oxygen were held in 5.00 L at a pressure not} \\ \text{exceeding 3.00 atm? (c) What capacity would be} \\ \text{required to hold this same amount if the conditions} \end{array}$$

were fixed at 100°C and 3.00 atm?

▪

$$(a) \quad P_2 = \frac{P_1 V_1 T_2}{T_1 V_2} = \frac{(1.00 \text{ atm})(22.4 \text{ L})(373 \text{ K})}{(273 \text{ K})(5.00 \text{ L})} = 6.12 \text{ atm}$$

$$(b) \quad T_2 = \frac{T_1 P_2 V_2}{P_1 V_1} = \frac{(273 \text{ K})(3.00 \text{ atm})(5.00 \text{ L})}{(1.00 \text{ atm})(22.4 \text{ L})} = 183 \text{ K} = -90^{\circ}\text{C}$$

$$(c) \quad V_2 = \frac{P_1 V_1 T_2}{T_1 P_2} = \frac{(1.00 \text{ atm})(22.4 \text{ L})(373 \text{ K})}{(273 \text{ K})(3.00 \text{ atm})} = 10.2 \text{ L}$$

12.41 A certain container holds 3.87 g neon at STP. What mass of neon will

it hold at 100 °C and 10.0 atm?

$$V_2 = \frac{P_1 V_1 T_2}{T_1 P_2} = \frac{(1.00 \text{ atm})(V_1)(373 \text{ K})}{(273 \text{ K})(10.0 \text{ atm})} = 0.137 V_1 \text{ or } 13.7\% \text{ of the original volume}$$

▪

Thus the container will have room for $(3.87 \text{ g})\left(\frac{V_1}{0.137 V_1}\right) = 28.2 \text{ g}$

Note: A more direct way to solve this problem is by using the ideal gas law (Sec. 12.3) twice.

12.42 At a certain altitude in the upper atmosphere, the temperature is estimated to be -100 °C and the density just 10^{-9} that of the earth's

$$P_2 = \frac{P_1 V_1 T_2}{T_1 V_2} = \frac{P_1 T_2}{T_1} \left(\frac{d_2}{d_1}\right) = \frac{(760 \text{ torr})(173 \text{ K})}{(273 \text{ K})} \times 10^{-9} = 4.8 \times 10^{-7} \text{ torr}$$

atmosphere at STP. Assuming a uniform atmospheric composition, what is the pressure in torr at this altitude?

▪

12.43 The density of helium is 0.1784 kg/m³ at STP. If a given mass of helium at STP is allowed to expand to 1.400 times its initial volume by changing the temperature and pressure, compute its resultant density.

- The density of a gas law shows that the density of an ideal gas varies inversely with the volume.

$$\text{Resultant density} = (0.1784 \text{ kg/m}^3) \left(\frac{1}{1.400}\right) = 0.1274 \text{ kg/m}^3 \quad \text{Note that } 1 \text{ kg/m}^3 = 1 \text{ g/L.}$$

12.44 The density of a certain gas is 1.43 g/L at STP. Determine the density of oxygen at 17 °C and 800 torr.

- The combined gas law shows that the density of an ideal gas varies inversely with the absolute temperature and directly with pressure.

$$d_2 = d_1 \left(\frac{T_1}{T_2} \right) \left(\frac{P_2}{P_1} \right) = (1.43 \text{ g/L}) \left(\frac{273 \text{ K}}{290 \text{ K}} \right) \left(\frac{800 \text{ torr}}{760 \text{ torr}} \right) = 1.42 \text{ g/L}$$

12.45 If the density of a certain gas at 30 °C and 768 torr is 1.35 kg/m³, find its density at STP.

- Since the mass does not change, the density is inversely proportional to the

$$\frac{d_{\text{STP}}}{d_2} = \frac{V_2}{V_{\text{STP}}} \quad \frac{P_{\text{STP}} V_{\text{STP}}}{T_{\text{STP}}} = \frac{P_2 V_2}{T_2} \quad \text{volume:}$$

$$\frac{P_{\text{STP}} T_2}{P_2 T_{\text{STP}}} = \frac{V_2}{V_{\text{STP}}} = \frac{(760 \text{ torr})(303 \text{ K})}{(768 \text{ torr})(273 \text{ K})} = 1.10 \quad d_{\text{STP}} = 1.10 d_2 = (1.10)(1.35 \text{ kg/m}^3) = 1.48 \text{ kg/m}^3$$

12.46 At the top of a mountain the thermometer reads 0 °C and the barometer reads 710 mmHg. At the bottom of the mountain the temperature is 30 °C and the pressure is 760 mmHg. Compare the density of the air at the top with that at the bottom.

- Density is inversely proportional to volume:

$$\frac{d_{\text{top}}}{d_{\text{bottom}}} = \frac{V_b}{V_t} = \frac{T_b P_t}{T_t P_b} = \frac{(303 \text{ K})(710 \text{ mmHg})}{(273 \text{ K})(760 \text{ mmHg})} = 1.04 \quad \text{The density ratio is 1.04 to 1.}$$

12.47 At 0 °C the density of nitrogen at 1.00 atm is 1.25 kg/m³. The nitrogen which occupied 1500 cm³ at STP was compressed at 0 °C to 575 atm, and the gas volume was observed to be 3.92 cm³, in violation of Boyle's law. What was the final density of this nonideal gas?

- Since the mass of the nitrogen is constant,

$$\text{Final density} = \frac{\text{initial mass}}{\text{final volume}} = \frac{(1.25 \text{ kg/m}^3)(1500 \times 10^{-6} \text{ m}^3)}{3.92 \times 10^{-6} \text{ m}^3} = 478 \text{ kg/m}^3$$

12.48 A volume of 95 cm^3 of nitrous oxide at 27°C is collected over mercury in a graduated tube, the level of mercury inside the tube being 40 mm above the outside mercury level when the barometer reads 750 torr. (a) Compute the volume of the same mass of gas at STP. (b) What volume would the same mass of gas occupy at 40°C , the barometric pressure being 745 torr and the level of mercury inside the tube 25 mm below that outside?

- Remember that $1 \text{ torr} = 1 \text{ mmHg}$.

$$(a) \quad P_1 = (750 \text{ torr}) - (40 \text{ torr}) = 710 \text{ torr} \quad V_2 = \frac{P_1 V_1 T_2}{T_1 P_2} = \frac{(710 \text{ torr})(95 \text{ cm}^3)(273 \text{ K})}{(300 \text{ K})(760 \text{ torr})} = 81 \text{ cm}^3$$

$$(b) \quad P_2 = (745 \text{ torr}) + (25 \text{ torr}) = 770 \text{ torr} \quad V_2 = \frac{(710 \text{ torr})(95 \text{ cm}^3)(313 \text{ K})}{(300 \text{ K})(770 \text{ torr})} = 91 \text{ cm}^3$$